BAMBOO (BETUNG SPECIES) FIBER COMPOSITE PLATE FOR EXTERNAL STRENGTHENING OF RC BEAMS

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor Degree of Civil Engineering

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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Thesis submitted in fulfillment of the requirements
for the award of the
Bachelor Degree in Civil Engineering

Faculty of Civil Engineering and Earth Resources

UNIVERSITI MALAYSIA PAHANG

JUNE 2018

ACKNOWLEDGEMENTS

I would like to take this opportunity to acknowledge all the parties who helped me in completing this research. First, I would to express my appreciation to my supervisor, Dr. Chin Siew Choo for her guidance, idea and support throughout this research. Through her useful recommendation, knowledge and informative discussion, I am being able to complete this study.

Next, I would like to express my gratitude towards my university, Universiti Malaysia Pahang for providing me a platform to conduct and complete this research. Also, with all the facilities, equipment and machineries, I am being able to carry out all the relevant tests. Not to forget the concrete lab staffs for their professional guidance and clear instructions during the laboratory works.

Apart from that, I would like to thank all the lecturers whom have taught me in every semester. They have indeed helped me to understand more on the knowledge and theories in this field of study.

Lastly, special thanks to all my friends who are always willing to help and share their knowledge, even help for heavy lab works. They have indeed helped me to save time and cost for completing this study. I am also grateful to my family for their encouragement and support all the way to the completion of my study.

ABSTRAK

Gentian semula jadi telah digunakan untuk menggantikan gentian sintetik dalam pembuatan komposit kerana gentian semula jadi lebih mesra alam berbanding dengan gentian sintetik. Satu penyelidikan telah dijalankan untuk mengenal pasti sifat mekanikal buluh spesies Betung dan potensinya untuk difabrikasikan sebagai komposit berasaskan gentian buluh (BFCP) sehubungan dengan penggunaannya dalam menambahkan kekuatan luaran rasuk konkrit bertelulang. Dalam kajian ini, buluh yang digunakan diperoleh dari Raub, Pahang. Ciri-ciri mekanikal buluh mentah dan kering telah dikaji melalui ujian mampatan dan ujian tegangan. BFCPs dalam nisbah isipadu gentian 0.4 telah difabrikasikan dan diuji dengan ujian lenturan (ASTM D790-03) dan ujian tegangan (ASTM D3039) untuk menentukan sifat-sifat mekanikalnya. Ujian pemuatan empat titik telah dijalankan untuk mengkaji kekuatan rasuk konkrit bertetulang yang dipasang dengan BFCP. Hasil kajian menunjukkan bahawa buluh spesies Betung mempunyai kepadatan sebanyak 0.807 g/cm^3. Dalam ujian mampatan, sampel buluh yang diuji gagal dalam dua mod, iaitu penghancuran gentian dan retakan gentian. Sampel buluh yang kering telah mencapai kekuatan mampatan sebanyak 19.5 % berbanding dengan sampel buluh yang mentah. Sebaliknya, keputusan menunjukkan bahawa kekuatan tegangan sampel mentah telah bertambah sebanyak 45 % berbanding dengan sampel yang kering. Selain itu, dalam ciri-ciri mekanikal, BFCP telah menunjukkan ketinggian sebanyak 666 % dan 178 % dalam kedua-dua kekuatan lenturan dan kekuatan tegangan berbanding dengan sampel epoksi. Pengekatan antaran serat buluh dengan resin epoksi dalam BFCP telah menambahbaikkan ikatan struktur dan ciri-ciri mekanikalnya. Melalui ujian pemuatan empat titik, data menunjukkan bahawa rasuk konkrit bertetulang yang ditampalkan dengan BFCP sebanding dengan rasuk konkrit kawalan dengan nisbah kekuatan sebanyak 96 % dan 97 %. Kajian juga menunjukkan kekuatan rasuk konkrit yang diperkuatkan dengan BFCP telah meningkat sebanyak 10-12 % berbanding dengan rasuk konkrit yang tanpa sebarang pengukuhan. Dalam pemerhatian corak-corak retakan, hanya sedikit retakan yang muncul di bahagian yang ditampal dengan BFCP. Pemasangan BFCP mampu mengalihkan retakan tegak ke pinggir plat dengan membentuk retakan pepenjuru. Ini membuktikan bahawa aplikasi BFCP sangat berkesan untuk menambahbaikkan kekuatan lenturan dan ia berpotensi untuk digunakan sebagai bahan pengukuhan luaran untuk memulihan kekuatan rasuk konkrit bertetulang.

ABSTRACT

Natural fibers are being introduced to replace the synthetic fiber in the manufacturing of fiber composites due to its environmental friendly behavior. A research had been conducted to investigate the mechanical properties of bamboo (Betung species) and its potential to be used as bamboo fiber composite plate (BFCP) for the external strengthening of reinforced concrete (RC) beams. Raw bamboo culms were obtained from Raub, Pahang. Mechanical behaviour of raw and dried bamboo specimens was tested under compression test and tension test. All the BFCPs with 0.4 fiber-to-volume ratio have been fabricated and tested for flexural test (ASTM D790-03) and tensile test (ASTM D3039) to determine the mechanical properties. Four-point loading test was conducted to study the behaviour of reinforced concrete (RC) beam under external strengthening effect with BFCP. The result showed that bamboo of Betung species has a density of 0.807 g/cm^3. In compression test, bamboo culms fail in two modes: fiber cracking and fiber crushing. Dried bamboo specimens recorded 19.5 % higher in compression strength than raw bamboo specimens. There was an improvement of 45 % of average tensile strength in raw bamboo samples compared to dried specimens. In terms of mechanical behaviour, BFCP has higher flexural and tensile strength than pure epoxy samples where the flexural and tensile strength of BFCP increased by 666 % and 178 % respectively. The interfacial adhesion between the bamboo fiber and epoxy resin in BFCP greatly improved the structural bonding and mechanical properties. From the four-point loading test, BFCP strengthened beams had achieved the total load bearing capacity of 96 % and 97 % compared to solid control beam. Compared with un-strengthened beam, the load bearing capacity of BFCP strengthened beam increased by 10 % and 12 %. Installation of BFCP manage to divert the vertical cracks at the tension zone to the edge of the plate forming diagonal cracks. This proved that BFCP has potential to be used as external strengthening material in RC beams.

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LIST OF SYMBOLS

%	Percentage
mm	Millimeter
m	meter
N/mm2	Newton per millimeter square
g/cm3	Gram per centimeter cube
mL	Milliliter
N	Newton
kN	Kilo Newton
°C	Degree Celsius
g	Gram
mm/min	Millimeter per minute
mm2	Millimeter square
MPa	Mega Pascal
D	Distance from the support (mm)
V	Volume

LIST OF ABBREVIATIONS

BFCP	Bamboo Fiber Composite Plate
BFCPs	Bamboo Fiber Composite Plates
CAN	Chemical Assisted Natural
CB	Control Beam
CFRC	Carbon Fiber Reinforced Composite
CO_2	Carbon Dioxide
GFRC	Glass Fiber Reinforced Composite
INBAR	International Network for Bamboo and Rattan
LBC	Laminated Bamboo Composite
NFRCs	Natural Fiber Reinforced Composites
NaOH	Sodium Hydroxide
NFCP	Natural Fiber Composite Plate
RC	Reinforced Concrete
RM	Ringgit Malaysia
SFCP	Synthetic Fiber Composite Plate
SFCPs	Synthetic Fiber Composite Plates
ST-B	Strengthened Beam
US$	United States Dollar
UST-B	Un-strengthened Beam
UTM	Universal Testing Machine

CHAPTER 1

INTRODUCTION

1.1 Research Background

Due to the concerns over environment, there has been a lot of research in recent years towards the potential of natural fiber as an alternative to synthetic fiber especially in construction industries. Synthetic fibers that commonly used are polyethylene, aramid, polyesters, carbon and others hybrid fibers. Synthetic fibers are used due to their high performance in terms of strength, susceptible to fungus attack and water resistance. However, the mode of disposal of these artificial fibers becomes an issue which may threaten the environment because they are non-biodegradable. Hence, there are extensive of studies on the application of natural plant fibers like jute, kenaf, sisal, silk and bamboo fiber as an alternative to the synthetic fibers (Tong, 2017). Compare with artificial fibers, nature fibers tend to be more environmental friendly as they are biodegradable, renewable, and readily available in natural form and possess adequate strength. They offer more economical and environmental advantages and start to become emerging materials in engineering field (Lau *et al.*, 2018).

A study by Mohamed and Appanah (1998) showed that only 0.6 million tons of bamboo stocks in Malaysia that are being used commercially instead of the total amount of 7.0 million tons. Based on the statistic, this quantity has reached an estimated value of RM 3 million. Due to the rapid growth rate of bamboo and its great productivity, bamboos production has reached a huge amount of 30,000,000 tons (Faruk *et al.*, 2012). Bamboos are the largest green grass family *Poaceae* in the subfamily *Bambusoideae.* There are more than thousand species of bamboo found in diverse climate (Eichhorn *et al.*, 2001). Out of these, 18 bamboo species have been used as fiber for composites. Therefore, suitable and convenient methods should be implemented to fabricate bamboo composites and optimize its benefit as natural resources (Okubo, Fujii and Yamamoto, 2004).

Bamboo fibers are also called `natural glass fiber` due to its longitudinal alignment of fibers which produces high strength with respect to its weight. High performance composite parts are produced from these fiber configurations at low implementation cost with the help of advance technology (Perremans *et al.*, 2018). Compare to other natural fibers, bamboo fiber also has lower cellulose content and a smaller microfibrillar angle which contribute to both volume resistivity and mechanical strength. Those cellulose fibers inside the bamboo composite material are embedded in lignin matrix, aligned along the length of the bamboo which then produces maximum flexural strength, rigidity and tensile (Ray, Das and Mondal, 2004). Due to the superior tensile strength and modulus of elasticity, bamboo fibers become common materials used in polymeric composites (Deshpande et al. 2000). Another research showed that the tensile strength of bamboo fiber reached a high value about 330 MPa which is higher than other natural fiber reinforced green composites (Cao, Shibata and Fukumoto, 2006).

Bio-composites made of bamboo fibers are considered as green and environmentally responsible eco-products. Epoxy resins are used as the matrix in the fabrication of composite plates. With the combination of two materials, it can enhance the stiffness, flexural, tensile strength, and resistance to corrosion of the composites plate. They are preferable to be installed externally as structural material to strengthen the reinforced structures due to its light weight, ease in installation, high strength and abundant resources (Chin *et al.*, 2012). Therefore, it is possible to increase the number of application for bamboo fiber reinforced composite plate to replace the costly and non-biodegradable synthetic fibers. In the latest development, the interest of utilizing natural fiber was shifted to the aerospace industry (interior), automotive, marine and even civil construction materials (Bansal, Ramachandran and Raichurkar, 2017).

The strengthening of existing civil structures must be considered when environment factors such as moisture and weathering affect the lifespan of the whole buildings (Alam and Al Riyami, 2018). To extend the design life of the structure, several strengthening methods like applying the bolts, widening the span and externally bonded fiber reinforced plates on RC structures have been implemented (Jumaat and Alam, 2008). These applications tend to repair and upgrade the existing structures in term of design life time and load bearing capacity.

1.2 Problem Statement

The fabrication of composite plate is commenced by using synthetic fibers due to their high strength, stiffness and longer life span. Moreover, synthetic fiber composite plates (SFCPs) tend to be more resistant to corrosion, water, adverse environment and thermal stability (Begum K and Islam MA, 2013). These unique characteristics enable them to be adapted and equipped easily on most structures. Despite these advantages, SFCPs have plenty of drawbacks and the biggest restriction is the high production cost. They are also non-biodegradable as this would lead to environment hazards as the fabrication process produces a significant amount of carbon dioxide gaseous (CO_2). Based on these reasonable analyses, renewable natural plant fibers composites are increasingly gaining attention as viable alternative to SFCPs over years.

Although natural plant fibers especially bamboo fibers are taking advantage of strong material properties and environmental friendly, it has a low comprehensive utilization rate and automation. The problem is that the bamboo industry produces no high value products and it fails to maximize the ecological and economic strengths (Wang et al., 2013). Although a great work has been made on potential of natural fiber composite materials as alternative solution in construction industries, research on the suitability of bamboo fiber composite plates (BFCP) for externally strengthening the reinforced concrete structures is rare.

All these issues have led to explore of possible BFCP to replace some of the traditional engineering materials that are not environmentally friendly which used and resolve these issues. Natural plant fibers have unequivocally contributed economic prosperity and sustainability in our daily lives. To this end, in the present research work, an attempt has been made to reveal the physical and mechanical properties of bamboo fiber as well as the potential of BFCP to be used as external strengthening materials on RC structures.

1.3 Research Objectives

The aims of this research are to study the mechanical properties of bamboo specimens (Betung species) as well as the fabricated bamboo fiber composite plate (BFCP) followed by the applicability of its composite plates for external strengthening on RC beams. The objectives of the research work are specified as follow:

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